RTCA Special Committee 186, Working Group 5

ADS-B UAT MOPS

Meeting #3

Validating the Independent Range Validation

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SUMMARY
Independent ranging is a viable option for UAT, but we must first understand how to make it work and what requirements are needed to ensure it's reliability

Objective:

The purpose of this study is to determine the feasibility of determining a UAT transmitting target's validity by comparing received GPS-derived information to the flight time of the transmitted signal. The UAT system contains a mechanism—namely the use of MSOs and receiver time-stamping—for being able to determine the time it took for the signal to propagate from receiver to transmitter. The question is whether we can place robust enough requirements on these functions are to allow reliable range validation.

Procedure:

The data used in this particular study comes from UAT flight trials conducted on October 20, 2000 in Toulouse, France. In this report, we will look at 5 different times during the day. Each data set is a record of messages received by a particular aircraft (Metroliner 1), including it's own transmissions. There are three transmit-receive (Tx-Rx) pairs available for study—Metroliner 1 to a ground station, a ground vehicle, and another aircraft.

For each Tx-Rx pair, each time a long ADS-B message is received from the target, the propagation time is determined by subtracting the time of receipt from the MSO time, and the range is determined in NM by multiplying the time in μs by c = 0.16815 NM/μs. Range is determined again by extrapolating the transmitter's position to the MSO time, extrapolating the receiver's position (derived from its own last transmission) to the time of receipt, and calculating the slant range between the two positions. If the difference between these two calculations is small enough, it can be determined that the target is transmitting true information. Extrapolation is performed on latitude and longitude only, using the reported NS and EW velocity, and the assumption that there are 60 NM per degree of latitude, and 60*cos(*lat*) NM per degree of longitude. The slant range equations used are given at the end of this report.

Preliminary Results:

We consider these results preliminary and to be used to asses the requirements to be levied on a certified UAT transceiver, not as an example of how Independent Range Validation will work. The system which collected this data has not been fully tested in such areas as velocity and time-stamping, which are critical parameters to the results of this paper. Although we have uncovered some anomalous behavior in the data, it is apparent that this anti-spoofing technique is viable.

Variables:
R_G = GPS-derived range between targets
R_T = Time-derived range between targets
$\Delta R = R_G - R_T$

Plots given in Appendix.

The most obvious source of error we attribute to the relative synchronization between the transmitter and receiver. In a perfectly synchronized system, with zero timing errors, the expected value of ΔR (or $E[\Delta R]$) is 0. The data shows that, although $E[\Delta R]$ is not equal zero, it is a relatively consistent value for a particular Tx-Rx pair. This could be caused by a nearly constant Δt relative synchronization offset between the transmitter and receiver. The transmitter is synchronized to UTC + t_{Rx} μs and the receiver to UTC + t_{Tx} μs, leaving them synchronized to each other, but offset by $\Delta t = t_{Rx} - t_{Tx}$. Table 1 shows the mean value of ΔR per pair over the course of about one hour, and the corresponding $\Delta t = \Delta R/c$.

Table 1

Time	Ground Station -> Aircraft 1		Ground Vehicle -> Aircraft 1		Aircraft 2 -> Aircraft 1	
	NM	μs	NM	μs	NM	μs
13:43	0.9069	5.6032	-0.0840	-0.5191	-0.0247	-0.1526
13:59	0.8841	5.4622	-0.1220	-0.7537	-0.0648	-0.4003
14:17	0.7758	4.7935	-0.1390	-0.8589	-0.2455	-1.5171
14:36	0.7739	4.7819	-0.1565	-0.9670	-0.2217	-1.3700
14:57	0.7948	4.9106	-0.1841	-1.1375	-0.4024	-2.4860
Standard Deviation	0.0635	0.3920	0.0375	0.2319	0.1518	0.9379

For some of the ΔR calculations the values are derived from only part of the data. As can be seen in the plots, there are times when ΔR is changing. The figures in Table 1 come from the data points where ΔR is stabilized, and outliers are not included.

Trend changes in ΔR seem to be the result of Tx-Rx pair orientation. Refer to the plots in Appendix. The slope of the "Error" curve is steep when the slope of the "GPS_Range" curve is steep. The behavior of the "Error" curve also seems to depend on the parallel separation between transmitter and receiver, especially in the Aircraft plots. A mathematical relationship is evident, but we were not able to determine what it may be in time for this meeting. This is undesired behavior, and we can offer no explanation for its existence except that it seems to depend on the first and second derivative of Range as a function of time. Inaccuracies in the reported velocity is our prime suspect.

Outliers are generally overlooked in this study. There are different categories of stray data points. A small set of calculated ΔR's are in the range from 200 to 130,000 NM. These are obviously glitches, and are attributed to the R_T calculation. Another set of outlying data points occur during a couple of about 5-10 minute periods. These are all 10-225 standard deviations away from the mean of the well-behaved data, and all in the same direction. Again, it appears to be the result of a glitch in implementation. Otherwise, the data behaves as expected with small standard deviations on the order of 0.01 NM.

Conclusions:

If the mechanism that causes the Error curve to have a non-zero slope can be determined and corrected for, then independent range validation is a very viable capability of the UAT system. Straight sections of the curve have very small standard deviations (0.01 – 0.05 NM), and although this unexplained behavior impacts the calculation of the mean (from which dis-synchronization can be determined), the mean is relatively stable over the course of the day and could be easily compensated for. Even in the data as it is in this paper, the maximum absolute error calculated, without giving consideration to synchroniza-tion, is around 1 NM, and the largest spread over a 20 minute period is around 1 NM.

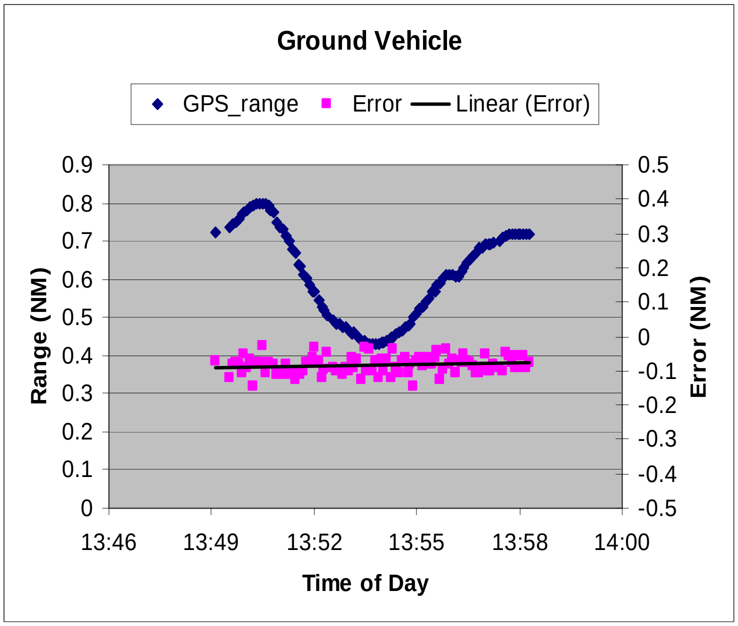
Appendix

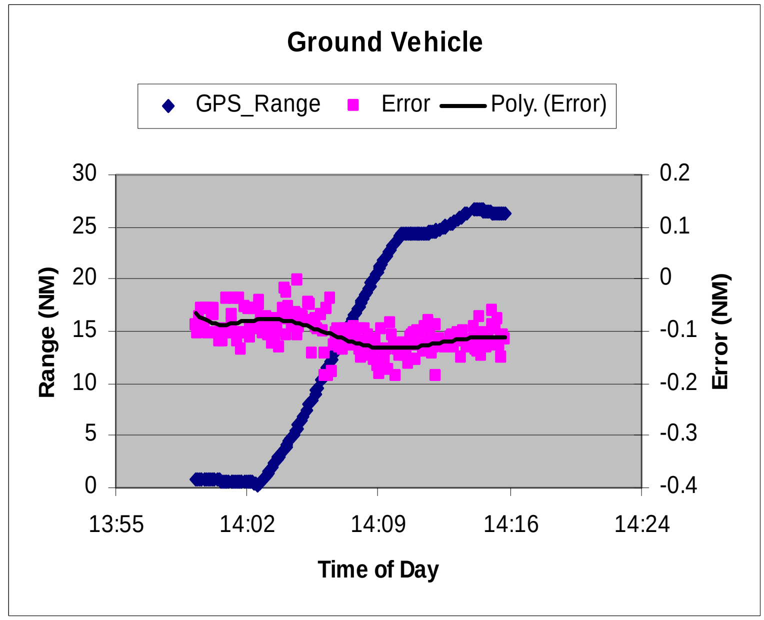
Equations for slant range calculations:

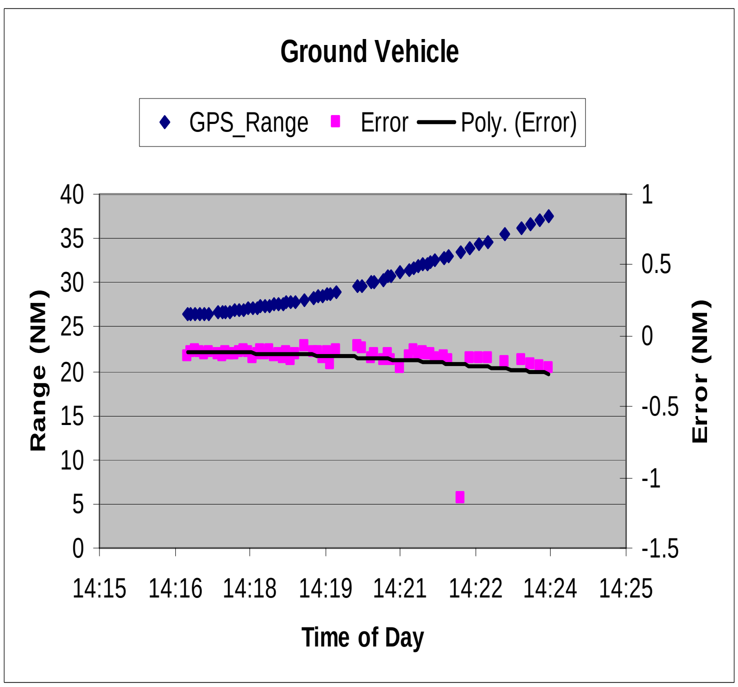
$$d = r_2\left[1+\left(\frac{r_1}{r_2}\right)^2 - 2\left(\frac{r_1}{r_2}\right)\cos(\gamma)\right]^{\frac{1}{2}}, \text{ where}$$

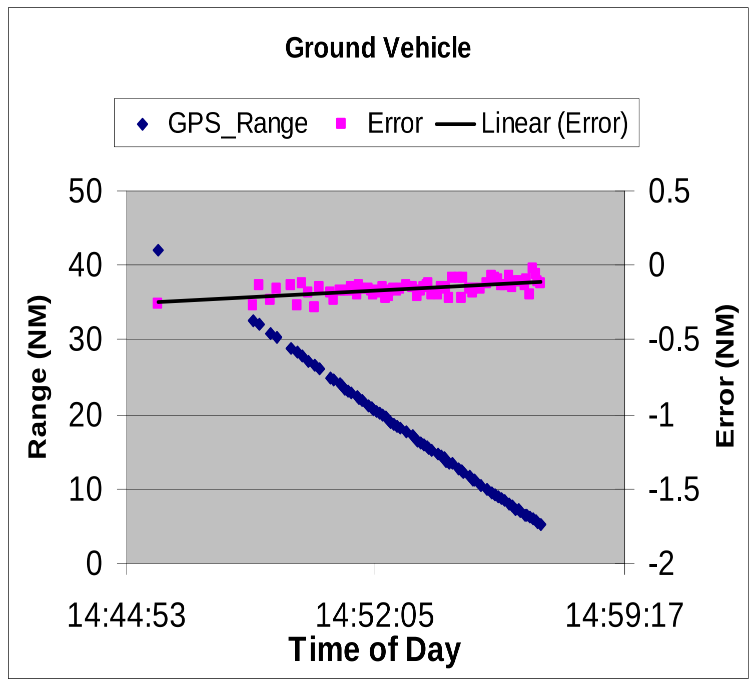
$$\cos(\gamma) = \cos(lat_1)\cos(lat_2)\cos(lon_2 - lon_1) + \sin(lat_1)\sin(lat_2)$$

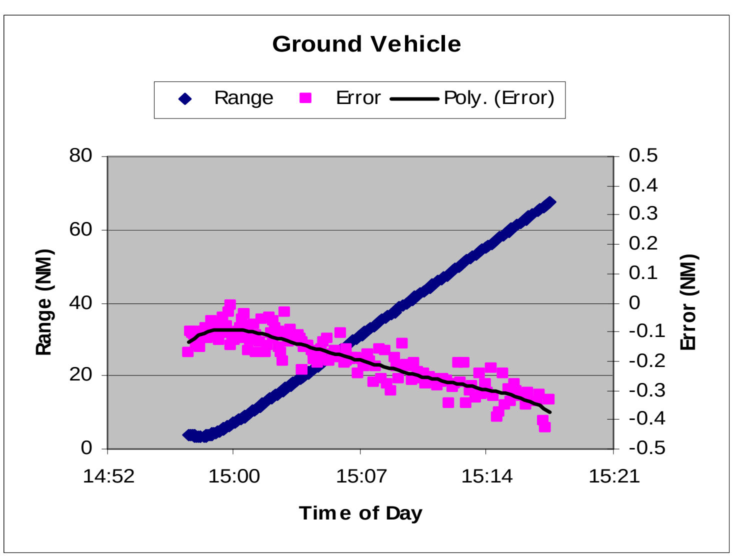
r1 = distance from center of earth to transceiver 1
r2 = distance from center of earth to transceiver 2
γ = angle between transceiver 1 and 2, measured at the center of the earth

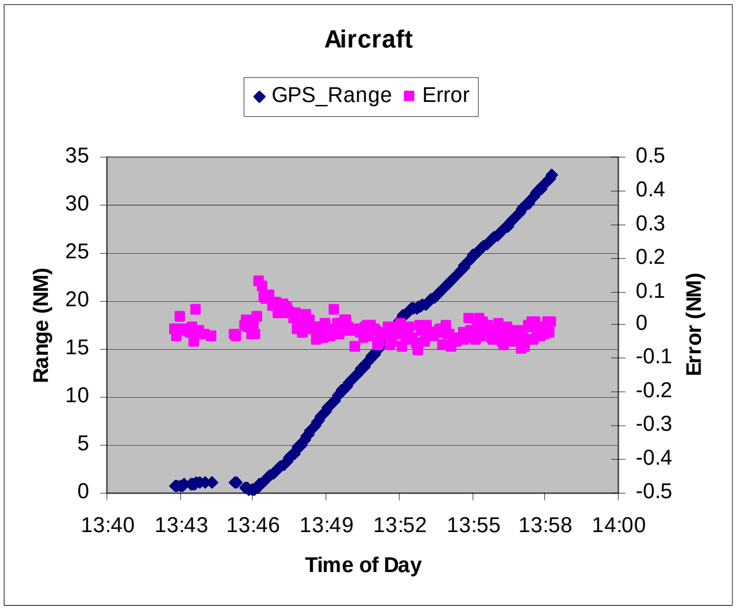

Ground Vehicle
GPS_range
Error
Linear (Error)
Range (NM)
Error (NM)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
13:46
13:49
13:52
13:55
13:58
14:00
Time of Day

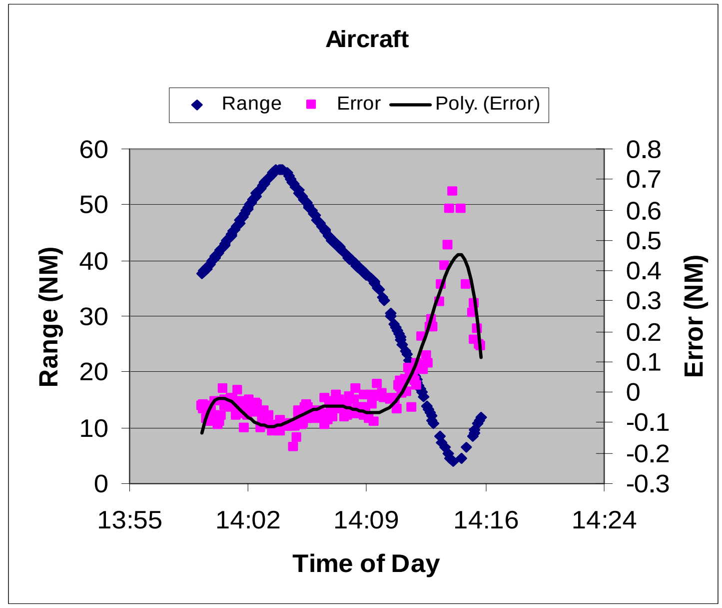

Ground Vehicle
GPS_Range
Error
Poly. (Error)
Range (NM)
Error (NM)
30
25
20
15
10
5
0
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
13:55
14:02
14:09
14:16
14:24
Time of Day

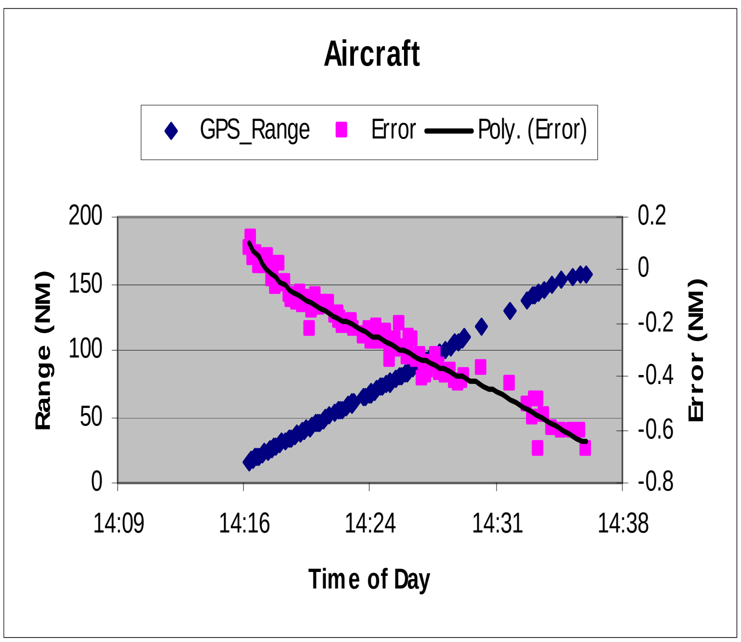

Ground Vehicle
GPS_Range
Error
Poly. (Error)
Range (NM)
Error (NM)
40
35
30
25
20
15
10
5
0
1
0.5
0
-0.5
-1
-1.5
14:15
14:16
14:18
14:19
14:21
14:22
14:24
14:25
Time of Day

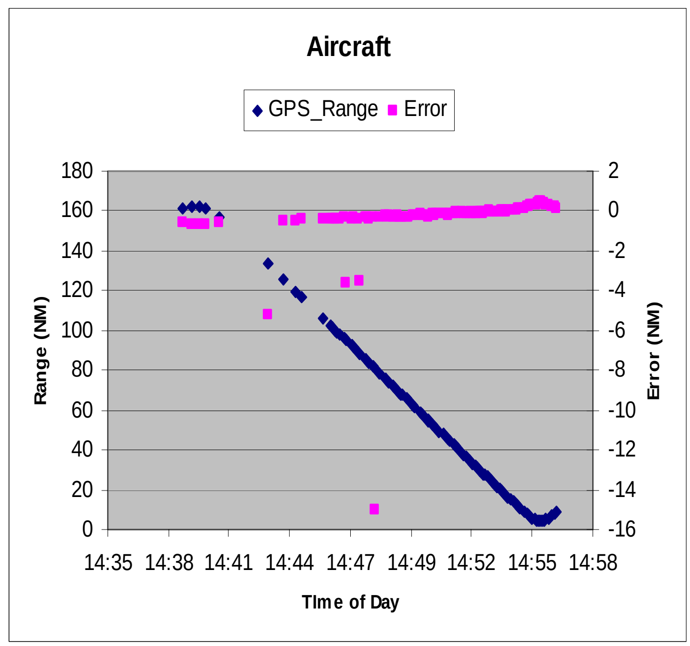

Ground Vehicle
GPS_Range
Error
Linear (Error)
Range (NM)
Error (NM)
50
40
30
20
10
0
0.5
0
-0.5
-1
-1.5
-2
14:44:53
14:52:05
14:59:17
Time of Day

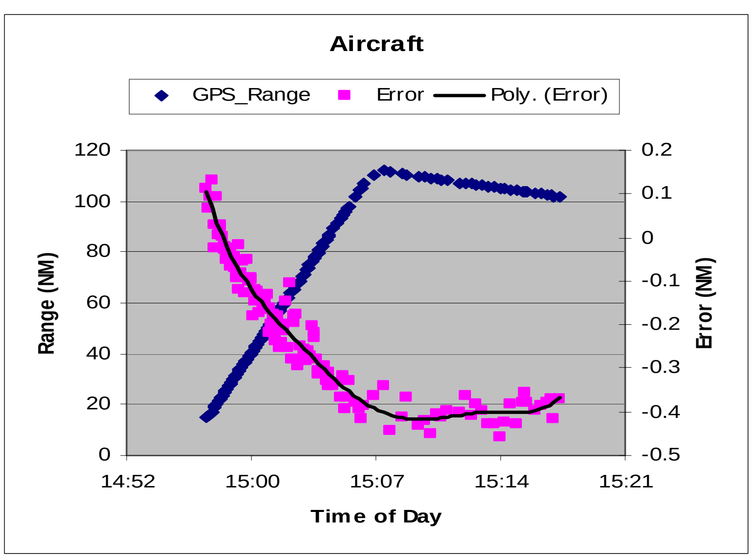

Ground Vehicle
Range
Error
Poly. (Error)
Range (NM)
Error (NM)
80
60
40
20
0
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
14:52
15:00
15:07
15:14
15:21
Time of Day

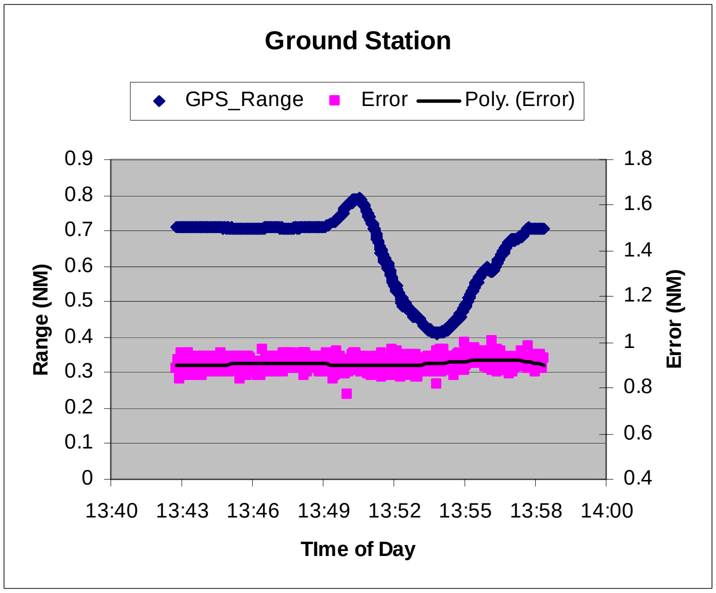

Aircraft
GPS_Range
Error
Range (NM)
Error (NM)
Time of Day
35
30
25
20
15
10
5
0
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
13:40
13:43
13:46
13:49
13:52
13:55
13:58
14:00

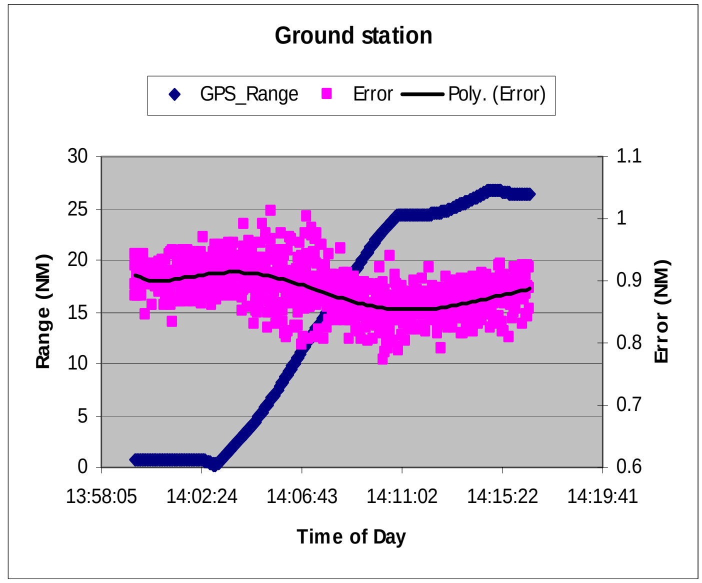

Aircraft
Range
Error
Poly. (Error)
Range (NM)
Error (NM)
Time of Day
60
50
40
30
20
10
0
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
13:55
14:02
14:09
14:16
14:24

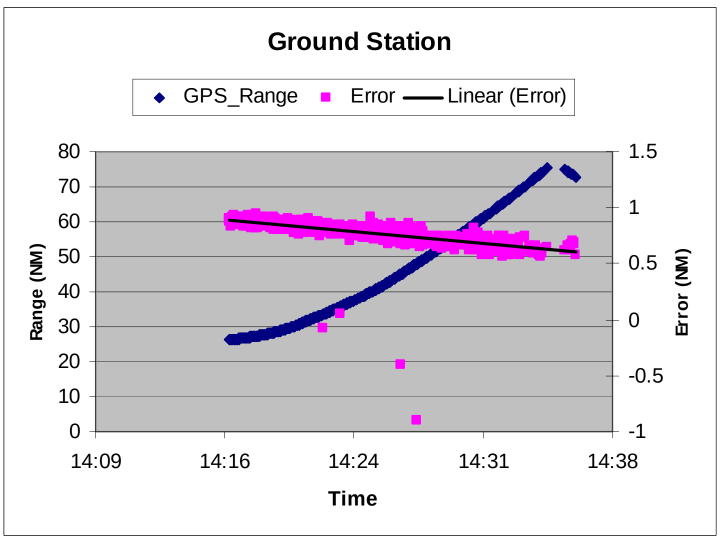

Aircraft
GPS_Range
Error
Poly. (Error)
Range (NM)
Error (NM)
Time of Day
200
150
100
50
0
0.2
0
-0.2
-0.4
-0.6
-0.8
14:09
14:16
14:24
14:31
14:38

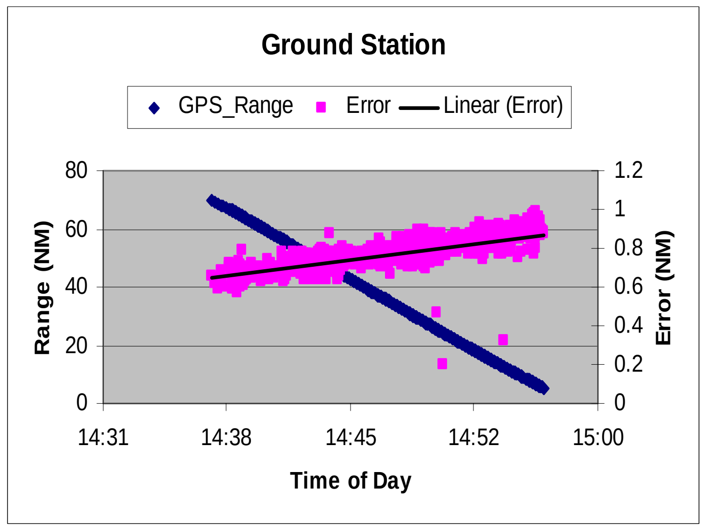

Aircraft
GPS_Range
Error
Range (NM)
Error (NM)
Time of Day
180
160
140
120
100
80
60
40
20
0
2
0
-2
-4
-6
-8
-10
-12
-14
-16
14:35
14:38
14:41
14:44
14:47
14:49
14:52
14:55
14:58

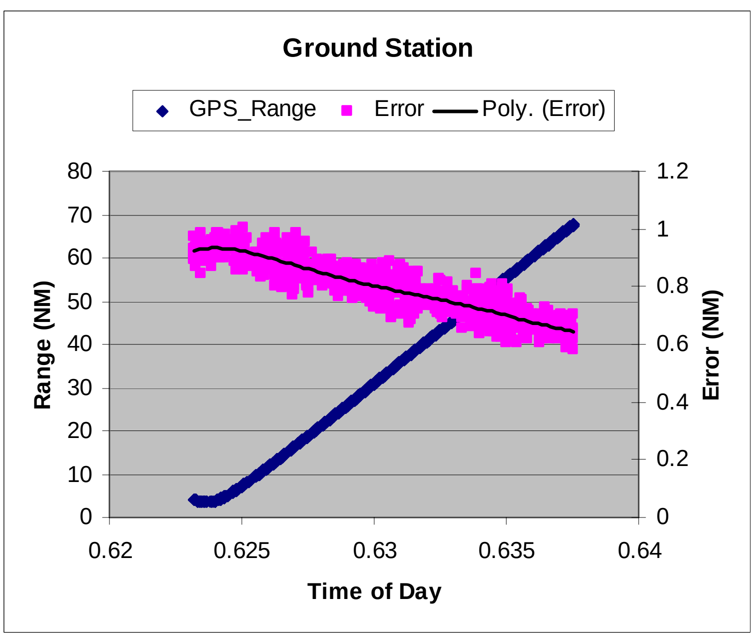

Aircraft
GPS_Range
Error
Poly. (Error)
Range (NM)
Error (NM)
Time of Day
120
100
80
60
40
20
0
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
14:52
15:00
15:07
15:14
15:21


Ground Station
GPS_Range
Error
Poly. (Error)
Range (NM)
Error (NM)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
13:40
13:43
13:46
13:49
13:52
13:55
13:58
14:00
TIme of Day


Ground station
GPS_Range
Error
Poly. (Error)
Range (NM)
Error (NM)
30
25
20
15
10
5
0
1.1
1
0.9
0.8
0.7
0.6
13:58:05
14:02:24
14:06:43
14:11:02
14:15:22
14:19:41
Time of Day


Ground Station
GPS_Range
Error
Linear (Error)
Range (NM)
Error (NM)
80
70
60
50
40
30
20
10
0
1.5
1
0.5
0
-0.5
-1
14:09
14:16
14:24
14:31
14:38
Time


Ground Station
GPS_Range
Error
Linear (Error)
Range (NM)
Error (NM)
80
60
40
20
0
1.2
1
0.8
0.6
0.4
0.2
0
14:31
14:38
14:45
14:52
15:00
Time of Day


Ground Station
GPS_Range
Error
Poly. (Error)
Range (NM)
Error (NM)
80
70
60
50
40
30
20
10
0
1.2
1
0.8
0.6
0.4
0.2
0
0.62
0.625
0.63
0.635
0.64
Time of Day